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Potential of vapour decontamination for improving IAQ – Making use of tea tree oil: The case of a healthcare facility

Y.H. Yau*, K.S. Phuah, L.C. Ding, Y.C. Lian, C.P. Chang

Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

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ABSTRACT

This paper describes a practical investigation into the indoor air quality of a fully air-conditioned eight-storey healthcare facility in the East Malaysia region before and after vapour decontamination. East Malaysia is located in a hot and humid climate, which favours the growth of bacteria, yeasts and moulds. The main purpose of the investigation is to identify the potential of tea tree oil vapour decontamination to improve the indoor air quality by reducing the active bacteria, yeast and mould concentrations in indoor air. A total of 336 samples have been taken inside the building for indoor air at 84 different locations and 24 samples have been taken for outdoor air at 12 locations, which are near the fresh air intakes of the air handling units. The vapour decontamination method is used in the present study.

Results show that the humidity levels remain high during the entire study period, exceeding 60% relative humidity, favouring the growth of bacteria, yeasts and moulds. By applying vapour decontamination from the air handling units to the ventilated air serving areas, the average bacteria, yeast and mould count is successfully reduced to below the recommended threshold of 500 CFU m^{-3} for normal zones, and 35 CFU m^{-3} for critical zones. The decontamination study result strongly suggests that the very real potential for applying tea tree oil vapour as air treatment in tropical countries like Malaysia for indoor air quality management in healthcare facilities.

1. Introduction

Air borne infectious diseases have become a growing concern after the spread of the influenza H1N1 and the severe acture respiratory syndrome (SARS) viruses. Research has shown that transmission through air was a significant factor contributing to the outbreaks [1,2]. In the early 19th century, humans had already identified air as a transport medium for infectious diseases [3], with important factors being the relative humidity and temperature [4]. Infectious diseases can spread directly or indirectly from one person to another. Bacteria, fungi and moulds are among the pathogenic microorganisms which cause infectious diseases [5]. Moulds, yeasts and bacteria are likely to build up in air conditioning systems, especially in the presence of high/sufficient humidity levels [6]. This suggests that hot and humid environments the in tropics, such as Malaysia, favour the growth of moulds, yeasts and bacteria in air conditioning systems.

The cleanliness of the space and air conditioning system of a healthcare facility is crucial. The performance of the ventilation, the dust loading conditions as well as biological contaminants all contribute to the air quality. Most biological contaminants, such as bacteria, moulds and yeasts, are categorized as potentially allergenic [7,8]. Continuous exposure to these biological contaminants can lead to irritation, allergies and infections [9].

Research on the relationship between temperature and relative humidity in the air has shown that high humidity favours the growth of bacteria, yeasts and moulds, and that a lower temperature will require a more humid environment to encourage such microbial growth [10,11]. Malaysia is located in a hot and humid climate region. Growth of fungi inside buildings in tropical climates is an issue of concern [12].

A hospital is a facility that requires exceptional caution in the control of infectious diseases, especially with regards to the design of the ventilation system to control possible contamination by air. However, humidity is not the only factor that influences the growth and spread of bacteria, because bacteria like *Staphylococcus aureus* and methicilin-resistant *S. aureus* (MRSA) can survive in dry environments for prolonged periods of time [13–15]. Decontamination is therefore required to decrease the survival chances of infectious agents.

The purpose of decontamination is to eliminate or minimize the level of biological contaminants on medical devices and room

* Corresponding author. Tel.: +60 3 79675210; fax: +60 3 79675317.
E-mail address: yhyau@um.edu.my (Y.H. Yau).

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surfaces. There are several steps of decontamination, which include a combination of cleaning, disinfecting and sterilizing. However, only a limited number of chemical disinfectants is available for air decontamination. A research study was carried out regarding air decontamination in healthcare buildings aiming to solve these issues, using hydrogen peroxide as the common solvent [16–20]. The European EN1276 and EN12054 standard suspension tests [21], and a trial for the clearance of MRSA colonization [22] showed that the tea tree oil had an antibacterial activity capability. The just mentioned studies have shown its significant potential to serve as an alternative agent for decontamination purposes. However, literature review reveals that the research work on using the tea tree oil vapour as the solutions of decontamination of indoor air microbial in the space is very rare.

For this purpose, the present study is conducted to investigate the potential of tea tree oil vapour as decontamination of indoor air microbial control in a newly-commissioned healthcare building.

2. Methodology and materials

The decontamination study was carried out in a newly-commissioned healthcare building, with the methodology being shown in Fig. 1. The healthcare building was launched for construction in 1998 and completed in three years. This is a fully air-conditioned eight-storey building with a level roof and can be categorized into critical and non-critical areas. The overall floor area of the healthcare facility is 41,450 m^2, with the critical area measuring about 4553 m^2.

The building does not contain a basement level. The first storey of the building contains the Information Technology (IT) Department, Medical Record Department, the Cancer Centre, mortuary, laboratory, material management and waste management, laundry and linen service, auditorium, and staff facilities. The second storey is where the cafeteria. Physiotherapy Department, Wellness and Heart Centre, Kidney and Stone Centre, Imaging Department, Accident and Emergency Department, Special Outpatient Clinic (SOC) and general administration are located. The third storey contains the Central Sterile Supply Department, the Invasive Cardiac Laboratory, Cardiac Catheterization Department and critical areas, which include the operating theatre, Coronary Care Unit and Intensive Care Unit. The fourth to the eighth storeys of the building are wards.

The air-conditioning system for the building is a centralized chilled water system, with the chiller plant located outside the main building. The chilled water is distributed to all air-handling units located throughout the building. Note that the measurements are conducted in an unoccupied condition and without operation (i.e. in the absent of major sensible and latent heat loads). Hence, the air conditions can be considered as an isothermal state in the room.

Each department is served by at least one Air Handling Unit (AHU). The building has a total of 72 AHUs, with 14 AHUs serving the critical areas located at level 3 of the eight-storey building. All AHUs are installed with primary and secondary filters. The operating theatres contain high efficiency particulate air (HEPA) filters, which the air has to pass through before being supplied into the work space.

2.1. Walkthrough inspection

A walkthrough inspection was carried out before samples were taken. The objective of the walkthrough was to identify the potential indoor sampling points according to the AHUs' serving area and also the outdoor sampling points according to the location of the AHUs [23]. Once the sampling points at the area of interest were identified, floor plans and drawings of the air-conditioning and the mechanical ventilation (ACMV) systems were collected.

2.2. Measurements

For the measurement of IAQ parameters, a total of 360 sampling points were taken. There were 336 indoor air measurements and 24 outdoor air measurements. All measurements were taken before and after the air decontamination process. There were also 84 locations sampled inside of the building, which could be subdivided into 58 locations within the general zone and 26

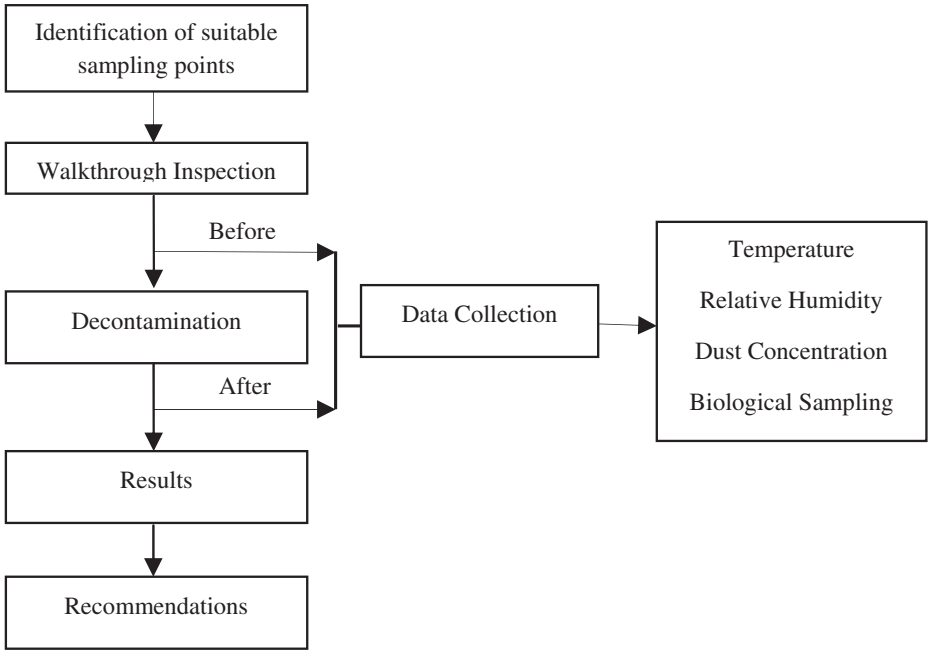

Fig. 1. Methodology for the decontamination study.

locations within the critical zone. Note that 12 sampling points were located outdoors near the fresh air intake of air handling units [23]. For the post sampling measurements, the central air-conditioning that served the relevant AHUs within the interest area had to be left running for at least 24 h after the decontamination process before the measurements were taken. For convenient reference, the sampling results, chosen locations and distribution of sampling points as well as other details are listed in Tables 1–5. It is pertinent to mention here that the sampling positions and number of samples are chosen based on the guide in the Malaysian Industry Code of Practice for Indoor Air Quality [23].

2.2.1. Temperature and relative humidity

The temperature and relative humidity of the indoor environment were measured using an Alnor Thermo-Anemometer, Model 440-A. This is a portable device used to measured temperature, relative humidity and air velocity.

2.2.2. Particulate matter

The concentration of the suspended particulates (total dust count) was measured using a TSI DuskTrakII Aerosol Monitor (Model 8532).

2.2.3. Biological sampling

The biological sampling was carried out using a single stage SAS Super 100 air sampler. The medium used for growing the bacteria was Plate Count Agar (PCA), while the growth medium used for yeasts and moulds was Sabouraud Dextrose Agar (SDA). The air sampler is able to draw air samples at the rate of 100 L m^{-3}, and the air samples get directly transferred to the PCA and SDA petri-dishes. The sampling was done in the region at around 75–120 cm above the floor [23]. The volume of air sampled was varied according to the nature of the air in the sampling area. The air volume taken from the operating theatre was 1000 L, while for other non-critical areas, the total volume was only 500 L. After sampling was done, air samples were incubated at different conditions. The PCA petri-dishes were incubated at 37 °C for 48 h, while the petri-dishes with SDA were incubated at 30 °C for 120 h. The microorganisms in the air samples were counted after incubation, and the unit for the measurement was in colony −forming units per cubic meter (CFU m^{-3}).

2.3. Decontamination procedure

The procedure for the decontamination process is shown in Fig. 2.

2.3.1. Cleaning and disinfection

For this study, the cleaning and disinfection of surfaces was done by wiping the devices with Trigene at a ratio of 1:20 Trigene to water. This was carried out before the misting process. All medical and electronic devices inside the general area were disinfected and wrapped. All surfaces (floors, walls and ceilings) in the room were wiped down. Floors were vacuumed to remove dust particles. For the critical areas, the wipe down was repeated three times.

2.3.2. Vapour decontamination

The room decontamination process was divided into two categories, namely general areas and critical areas. An electric fogging machine was used for the liquid decontamination solvent (tea tree oil) and converted it to mist. The just mentioned fogger built with three-counter rotating nozzles with a flow rate of 0–300 ml/min can deliver the particle size of 15–30 micron with the tank capacity of 4 L. The mist was then used for the decontamination of the indoor air. The fogging can attain distances of approximately 10 m and covers every inch of the room being fogged.

The general area covered included approximately 36,897 m^2 of floor area. The decontamination equipment was set up at the AHU chamber, with the windows and doors of the AHU serving area sealed to prevent leakage during the decontamination process. The mist produced at the AHU was then distributed to the room and general serving area through the ducting of the AHU. The AHU was left running for 24 h after the decontamination before sampling.

The critical area covered approximately 4,553 m^2 floor area, including the operating rooms and all surgical sites. The air ducts were misted from the AHU chamber. An additional decontamination step for the critical area was room space misting. The room air diffusers were sealed and robotic misting was carried out inside the rooms to further reduce other airborne contamination. The diffusers were reopened once the misting was complete and the air-conditioning was left running for the next 24 h.

For this research study, vapour decontamination was applied to the ducting and the areas served by each of the AHU units. The Gelair Solutions (i.e. the tea tree oil) was used to control microbial contaminants, such as moulds, yeasts and bacteria, which usually spread through the air-conditioning system. The just mentioned solution is a natural biodegradable gel, which consists of 10% pure tea tree oil from Australia in a gel base produced from seaweed.

3. Results and discussion

Table 1 presents the average values of the bacteria count, yeasts and moulds count and number of points sampled for each area before and after the process of vapour decontamination.

The average yeasts and moulds count for the outdoor environment was 673.3 CFU m^{-3}, exceeding the recommended standard of 500 CFU m^{-3} [24]. This suggests that the outdoor air introduced into the building may be one of the factors contributing to the active yeasts and moulds inside the building. High levels of yeasts

Table 1
Results of the microbial samplings.

	Bacteria		Yeasts and moulds	
	Matched before decontamination	Matched after decontamination	Matched before decontamination	Matched after decontamination
Outdoors				
No of points sampled	12	Nul	12	Nul
Average CFU/m^3	129.1	Nul	673.3	Nul
General area				
No of points sampled	58	58	58	58
Average CFU/m^3	120.3	18.5	70.8	34.4
Critical area				
No of points sampled	26	26	26	26
Average CFU/m^3	70.1	8.2	30.8	9

Table 2
List of total indoor air quality measurement points.

Level	Floor Plan	Department	Room	AHU	NOS. POINTS
1	1A	–	–	–	–
	1B	Material management	Corridor	1-AHU-MMG	1
		Laundry	Flat work	1-AHU-LDY	1
		Staff facilities	F. staff change/lockers	1-AHU-SFA	1
		Mortuary	Corridor in front of muslim body storage	1-AHU-MOR	1
	1C	Pharmacy	Ward supply disp. area	1-AHU-PHA	1
		Laboratory/Pathology	Corridor junction	1-AHU-LAB-1	1
			Main biochemistry lab	1-AHU-LAB-2	1
			Main bacteriology lab	1-AHU-LAB-2	1
		Administration	General office (Finace)	1-AHU-AAA	1
			General office (Admin & Operation)	1-AHU-AAA	1
		Medical record	Medical records	1-AHU-MDR	1
		I.T	Staff rest room	1-AHU-ITD-1	1
			CPU server room	1-AHU-ITD-1	1
	1D	Cancer centre	Nurse base	1-AHU-CAC-1	1
			Corridor in front of doctor office 2	1-AHU-CAC-2	1
			Linear accell. room 1	1-AHU-CAC-3	1
			Linear accell. room 2	1-AHU-CAC-4	1
			Treatment room	1-AHU-CAC-5	1
			Cyto lab	1-AHU-CAC-6	1
			Isol. room	1-AHU-CAC-ISOL	1
2	2A	Nursing admin	General office	2-AHU-TOW-1	1
			Main waiting	2-AHU-TOW-2	1
	2B	Wellness & heart centre	Treatment room	2-AHU-WCC-1	1
			Between two pat. prep/recovery	2-AHU-WCC-1	1
			Reception (Wellness)	2-AHU-WCC-2	1
		Kidney & stone centre	Nurse base	2-AHU-KSC-1	1
			Treatment room	2-AHU-KSC-2	1
	2C	Physiotherapy	Between gymnasium & corridor	2-AHU-PHY	1
			Public amenities (MPA)	2-AHU-PHY-CORR-1	1
			Public amenities (MPA)	2-AHU-PHY-CORR-2	1
		SOC 1, 2 & 3	Treatment room	2-AHU-OPD-1	1
			Treatment room	2-AHU-OPD-2−1	1
				2-AHU-OPD-2−2	–
				2-AHU-OPD-2−3	–
		Accident & emergency	Treatment cubicles 2	2-AHU-ACE	1
		Doctor's office	Corridor in front of doctor's office 3	2-AHU-SFA	1
			Corridor	2-AHU-SFA-CORR	1
	2D	Imaging	Sub wait group 1	2-AHU-IMG-1	1
			General radiography	2-AHU-IMG-1	1
			Equipt. store	2-AHU-IMG-1	1
			Work area group	2-AHU-IMG-2	1
	2E	General admin.	Admission counter	2-AHU-AAA	1
3	3A	CCU	Cubicle 5	3-AHU-TOW-1	1
			Isol. room 1	3-FCU-TOW-1	1
			Fluoro	3-FCU-TOW-2	1
		ICU	Isol. room 1	3-FCU-TOW-4	1
			Isol. room 2	3-FCU-TOW-5	1
			In front of bay 5	3-AHU-TOW-2	1
	3B	–		–	–
	3C	Operating theatre	Pre-op holding 2	3-AHU-OPT-1	1
			Post-anaesthesia recovery 3	3-AHU-OPT-2	1
			In front of anaes. work room	3-AHU-OPT-3	1
			To OT's corridor	3-AHU-OPT-4	1
			Operating room 1(General)	3-AHU-OT-1	2
			Operating room 2(General)	3-AHU-OT-2	2
			Operating room 3(Neurology)	3-AHU-OT-3	2
			Operating room 4(General)	3-AHU-OT-4	2
			Operating room 5(Cardiac)	3-AHU-OT-5	2
			Operating room 6(Orthopaedic)	3-AHU-OT-6	2
		Invasive cardiac laboratory	Invasive cardiac laboratory room	3-AHU-INV	1
		Cardiac catheterization	Corridor	3-AHU-CCL	1
		Central sterile supply	Ster items issue	3-AHU-CSD-STERILE	1
			Main packing area	3-AHU-CSD-L	1
			Trolley wash	3-AHU-CSD-R	1
	3D	Executive administration	Board room	3-AHU-AAA	1
4	4A	General care & day surgery unit	Treatment room	4-AHU-TOW-1	1
			Day lounge	4-AHU-TOW-1	1
		Paediatric ward	Corridor	4-AHU-TOW-2	1
			Corridor	4-AHU-TOW-2	1
5	5A	General care ward	Treatment room	5-AHU-TOW-1	1
			Day lounge	5-AHU-TOW-1	1
			Corridor	5-AHU-TOW-2	1
			Corridor	5-AHU-TOW-2	1

(*continued on next page*)

Table 2 (*continued*)

Level	Floor Plan	Department	Room	AHU	NOS. POINTS
6	6A	General care ward	Treatment room	6-AHU-TOW-1	1
			Day lounge	6-AHU-TOW-1	1
			Corridor	6-AHU-TOW-2	1
			Corridor	6-AHU-TOW-2	1
7	7A	General care ward	Treatment room	7-AHU-TOW-1	1
			Day lounge	7-AHU-TOW-1	1
			Corridor	7-AHU-TOW-2	1
			Corridor	7-AHU-TOW-2	1
8	8A	VIP ward	Treatment room	8-AHU-TOW-1	1
			Day lounge	8-AHU-TOW-1	1
			Corridor	8-AHU-TOW-2	1
			Corridor	8-AHU-TOW-2	1
				Total	88

and moulds might be due to the humid climate, which favours their growth. Table 1 shows that filters in the air handling units are efficient in reducing yeasts and moulds in the air to an acceptable level.

The bacteria count, however, did not show much variation for the indoor air in the general area. Only indoor air in the critical area supplied after passing through the HEPA filters show a removal effect of bacteria. The bacteria count showed that the bacteria loads of the outdoor and general area indoor air are all below the recommended threshold level.

3.1. General area

3.1.1. Evaluation of temperature and relative humidity

The temperature and relative humidity values measured are presented in Fig. 3. The measurements were taken twice, before and after the decontamination process.

The air dry-bulb temperature recorded in general areas in 58 locations ranged between 16.9 °C and 29.9 °C before the decontamination, with the average temperature being 23.2 °C. The ASHRAE [24] standard suggests a temperature range of 21–24 °C, which is lower than that recommended in the Singapore indoor air quality guidelines [25]. The Singapore indoor air quality guidelines were used since the environmental conditions in Singapore are more similar to those in Malaysia. The results deviated from the recommended temperature range for acceptable indoor air quality of 22.5–25.5 °C for the general area. Overall, regarding temperature, a total of 27 locations fell within the recommended temperature range prior to decontamination. During the period of IAQ (Indoor Air Quality) evaluation for post decontamination, the air dry-bulb temperature ranged from 17.5 °C to 27.5 °C, with an average of 22.9 °C, accounting for 37 sampling points satisfying the temperature requirements.

For both measurements, the relative humidity was far above the recommended range [24] of 30–60% RH, with the humidity values before and after decontamination reaching 70.5% and 77.4%, respectively. High humidity indicates problems occurring during the air cooling process, which results in the intake air not being properly dehumidified. Consequently, insufficient of dehumidification of the cooling coil causes the high humidity in rooms. The inadequate dehumidification also allows air at high humidity levels to pass through the cooling coil without any significant increase in temperature, resulting in air with high humidity being supplied into the room.

3.1.2. Evaluation of particulate matter

The recommended threshold limit for suspended particulate matter in the guidelines [23,25] is 150 $\mu g/m^3$. Fig. 4 shows the average concentration of indoor particulates, with the highest concentration of 62 $\mu g/m^3$ being measured before decontamination, and 47 $\mu g/m^3$ after decontamination. The average concentration at all locations before and after the decontamination process

Table 3
List of sampling points in general areas: Level 1.

Location information				
Level	Department	Room	AHU	Sampling locations
1	Material management	Corridor	1-AHU-MMG	1–1
	Laundry	Flat work	1-AHU-LDY	1–2
	Staff facilities	F. staff change/lockers	1-AHU-SFA	1–3
	Mortuary	Corridor in front of muslim body storage	1-AHU-MOR	1–4
	Pharmacy	Ward supply disp. area	1-AHU-PHA	1–5
	Laboratory/Pathology	Corridor junction	1-AHU-LAB-1	1–6
		Main biochemistry lab	1-AHU-LAB-2	1–7
		Main bacteriology lab	1-AHU-LAB-2	1–8
	Administration	General office (Finace)	1-AHU-AAA	1–9
		General office (Admin & Operation)	1-AHU-AAA	1–10
	Medical record	Medical records	1-AHU-MDR	1–11
	I.T	Staff rest room	1-AHU-ITD-1	1–12
		CPU Server room	1-AHU-ITD-1	1–13
	Cancer centre	Nurse base	1-AHU-CAC-1	1–14
		Corridor in front of doctor office 2	1-AHU-CAC-2	1–15
		Linear accell. room 1	1-AHU-CAC-3	1–16
		Linear accell. room 2	1-AHU-CAC-4	1–17
		Treatment room	1-AHU-CAC-5	1–18
		Cyto lab	1-AHU-CAC-6	1–19
		Isol. room	1-AHU-CAC-ISOL	1–20

Table 4
List of sampling points in general areas: Levels 2–8.

Location information				
Level	Department	Room	AHU	Sampling locations
2	Nursing admin	General office	2-AHU-TOW-1	2–1
		Main waiting	2-AHU-TOW-2	2–2
	Wellness & heart centre	Treatment room	2-AHU-WCC-1	2–3
		Between two pat. prep/recovery	2-AHU-WCC-1	2–4
		Reception (Wellness)	2-AHU-WCC-2	2–5
	Kidney & stone centre	Nurse base	2-AHU-KSC-1	2–6
		Treatment room	2-AHU-KSC-2	2–7
	Physiotherapy	Between gymnasium & corridor	2-AHU-PHY	2–8
		Public amenities (MPA)	2-AHU-PHY-CORR-1	2–9
		Public amenities (MPA)	2-AHU-PHY-CORR-2	2–10
	SOC 1, 2 & 3	Treatment room	2-AHU-OPD-1	2–11
		Treatment room	2-AHU-OPD-2-1	2–12
	Accident & emergency	Treatment cubicles 2	2-AHU-ACE	2–13
	Doctor's office	Corridor in front of doctor's office 3	2-AHU-SFA	2–14
		Corridor	2-AHU-SFA-CORR	2–15
	Imaging	Sub wait group 1	2-AHU-IMG-1	2–16
		General radiography	2-AHU-IMG-1	2–17
		Equipt. store	2-AHU-IMG-1	2–18
		Work area group	2-AHU-IMG-2	2–19
	General admin.	Admission counter	2-AHU-AAA	2–20
3	Invasive cardiac laboratory	Invasive cardiac laboratory room	3AHU-INV	3–1
	Cardiac catheterization	Corridor	3AHU-CCL	3–2
	Central Sterile supply	Ster items issue	3AHU-CSD-STERILE	3–3
		Main packing area	3AHU-CSD-L	3–4
	Executive administration	Board room	3AHU-AAA	3–5
4	General care & day surgery unit	Treatment room	4-AHU-TOW-1	4–1
		Day lounge	4-AHU-TOW-1	4–2
	Paediatric ward	Corridor	4-AHU-TOW-2	4–3
		Corridor	4-AHU-TOW-2	4–4
5	General care ward	Treatment room	5-AHU-TOW-1	5–1
		Day lounge	5-AHU-TOW-1	5–2
		Corridor	5-AHU-TOW-2	5–3
		Corridor	5-AHU-TOW-2	5–4
6	General care ward	Treatment room	6-AHU-TOW-1	6–1
		Day lounge	6-AHU-TOW-1	6–2
		Corridor	6-AHU-TOW-2	6–3
		Corridor	6-AHU-TOW-2	6–4
7	General care ward	Treatment room	7-AHU-TOW-1	7–1
		Day lounge	7-AHU-TOW-1	7–2
		Corridor	7-AHU-TOW-2	7–3
		Corridor	7-AHU-TOW-2	7–4
8	VIP ward	Treatment room	8-AHU-TOW-1	8–1
		Day lounge	8-AHU-TOW-1	8–2
		Corridor	8-AHU-TOW-2	8–3
		Corridor	8-AHU-TOW-2	8–4

Table 5
List of sampling points in critical areas: Level 3.

Location information				
Level	Department	Room	AHU	Sampling locations
3	CCU	Cubicle 5	3-AHU-TOW-1	3–1
		Isol. room 1	3-FCU-TOW-1	3–2
		Fluoroscopy	3-FCU-TOW-2	3–3
	ICU	Isol. room 1	3-FCU-TOW-4	3–4
		Isol. room 2	3-FCU-TOW-5	3–5
		In front of bay 5	3-AHU-TOW-2	3–6
	Operating theatre	Pre-op holding 2	3-AHU-OPT-1	3–7
		Post-anaesthesia recovery 3	3-AHU-OPT-2	3–8
		In front of anaes. work room	3-AHU-OPT-3	3–9
		To OT's corridor	3-AHU-OPT-4	3–10
		Operating room 1 (General)	3-AHU-OT-1	3–11, 12
		Operating room 2 (General)	3-AHU-OT-2	3–13, 14
		Operating room 3 (Neurology)	3-AHU-OT-3	3–15, 16
		Operating room 4 (General)	3-AHU-OT-4	3–17, 18
		Operating room 5 (Cardiac)	3-AHU-OT-5	3–19, 20
		Operating room 6 (Orthopaedic)	3-AHU-OT-6	3–21
	Invasive cardiac laboratory	Invasive cardiac laboratory room	3-AHU-INV	3–22
	Cardiac catheterization	Corridor	3-AHU-CCL	3–23
	Central sterile supply	Ster items issue	3-AHU-CSD-STERILE	3–24
		Main packing area	3-AHU-CSD-L	3–25
	Executive administration	Board room	3-AHU-AAA	3–26

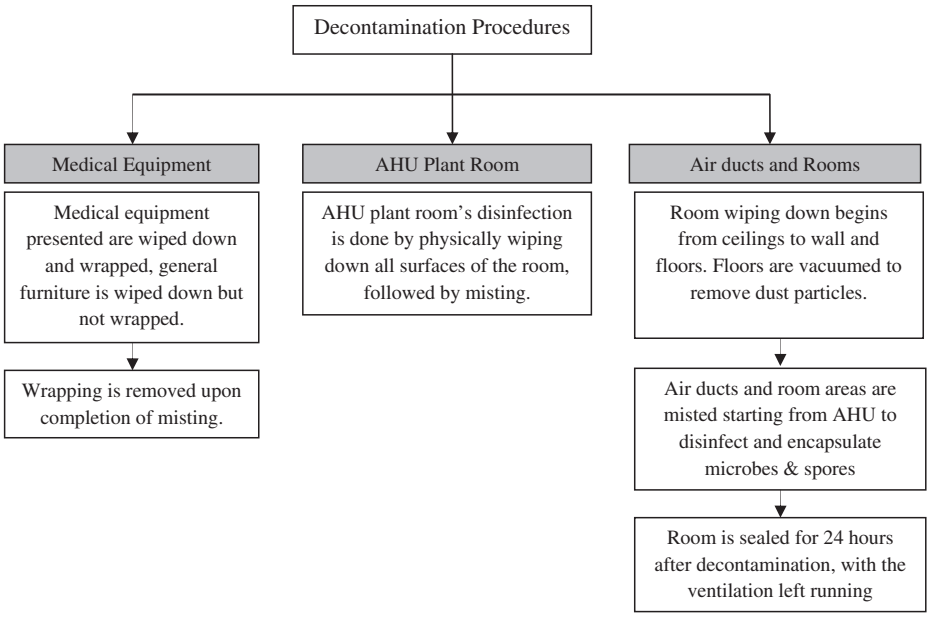

Fig. 2. Procedures for the decontamination process.

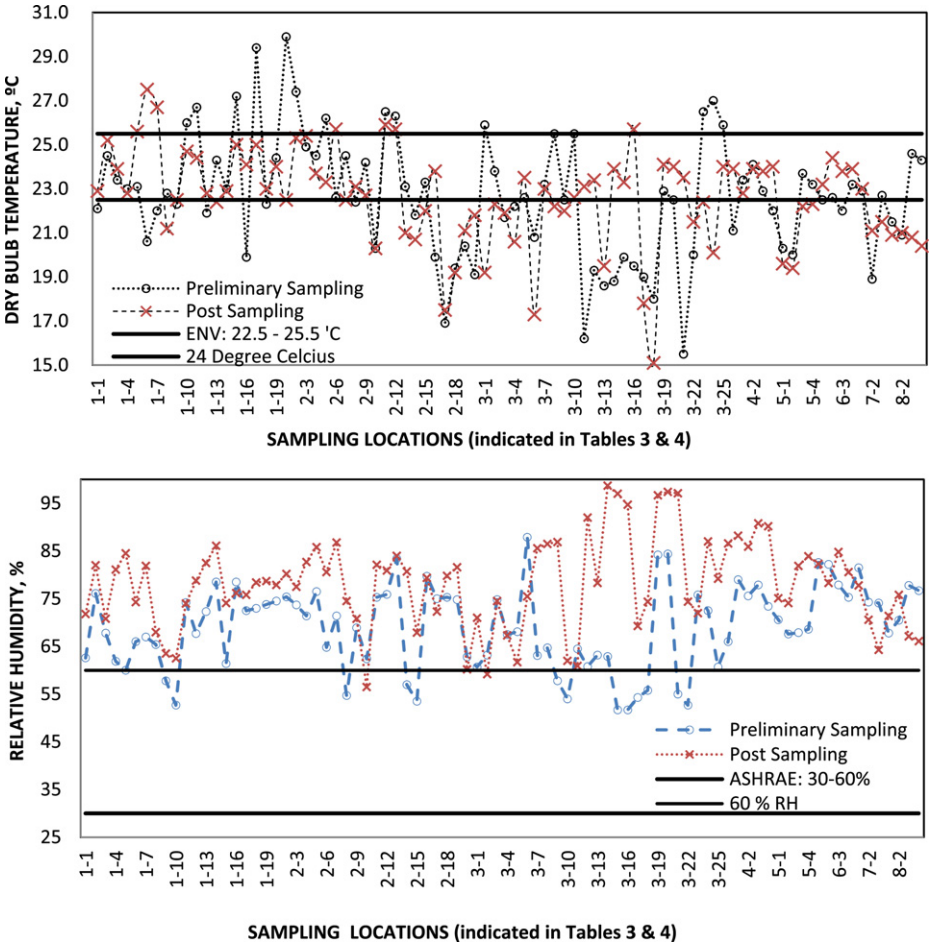

Fig. 3. Measurements for the air temperature and relative humidity for the building.

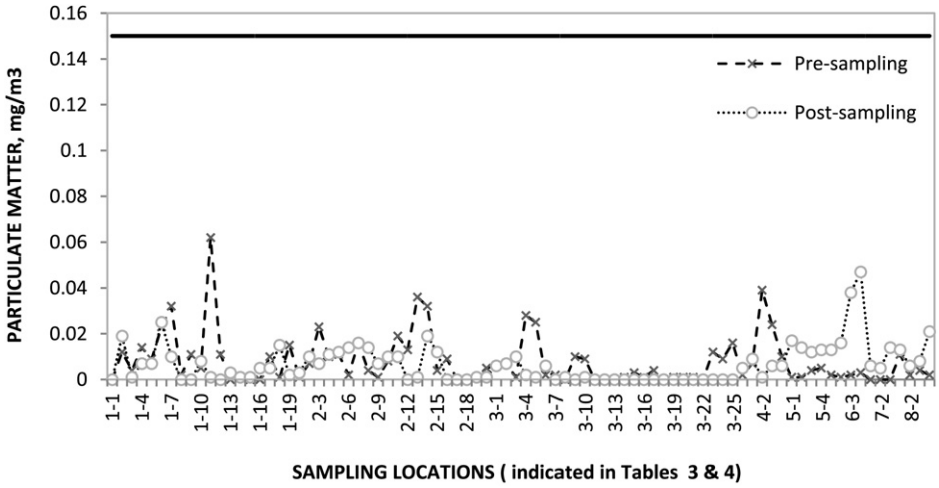

Fig. 4. Measurements of suspended particulate matters for the building.

was approximately the same, with values of 9 μg/m^3 and 8 μg/m^3, respectively. This has proven that particulate matter is not the main factor contributing to the reduction of the microbial count. It is important to mention that in this study, the average concentration of suspended particulate matter is similar before and after the decontamination.

3.1.3. Evaluation of microbial pollutants

The recommended threshold level [24] for total bacteria count and yeasts and moulds count is 500 CFU m^{-3} for general areas. It can be observed from Fig. 5 that after vapour decontamination, the values were all well below the 500 CFU m^{-3} threshold. The average bacteria count was reduced by 120%, from 120.3 CFU m^{-3} to 18.5 CFU m^{-3} (Table 1). Meanwhile, the average yeasts and moulds count was reduced by 51.4%, from 70.8 CFU m^{-3} to 34.4 CFU m^{-3} (Table 1). In addition, it also noted that in Fig. 5, the yeast and mould counts of post-sampling in more than 10 points are even higher than pre-sampling data. This is due to the fact that the vent used to supply the outdoor air is not sealed properly as well as the gap at the doors, and therefore, the microbial post sampling result shows an increase in fungus count compared to its microbial preliminary sampling result.

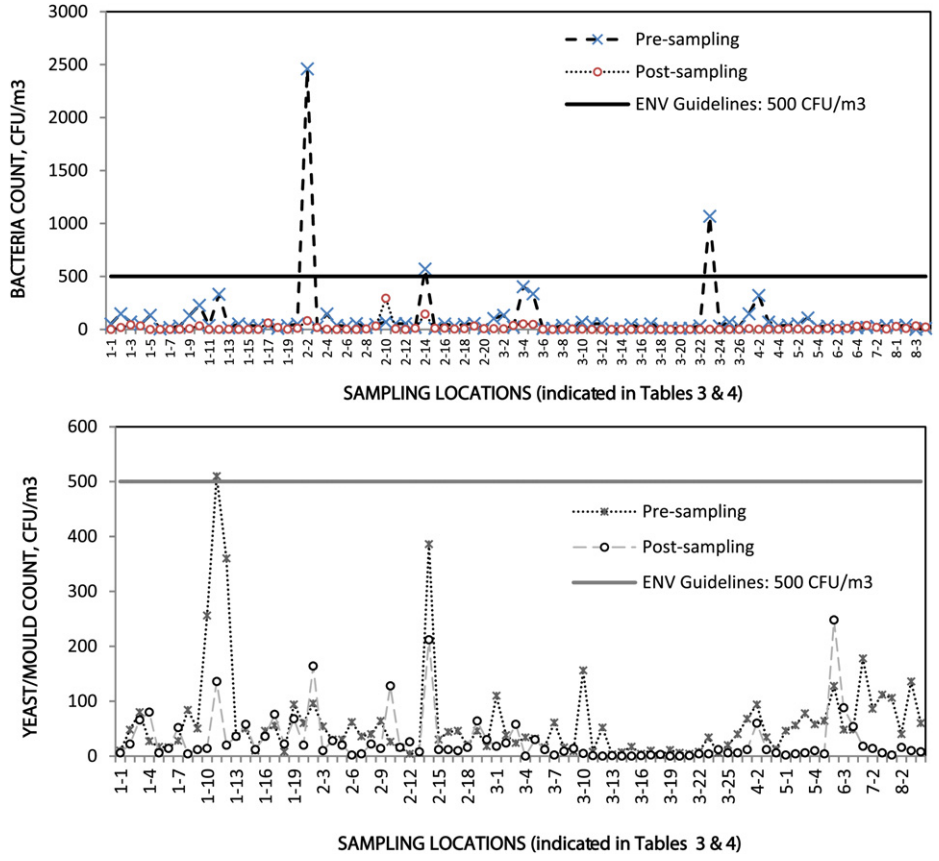

Fig. 5. Measurements of bacteria and fungus & mould counts for the building.

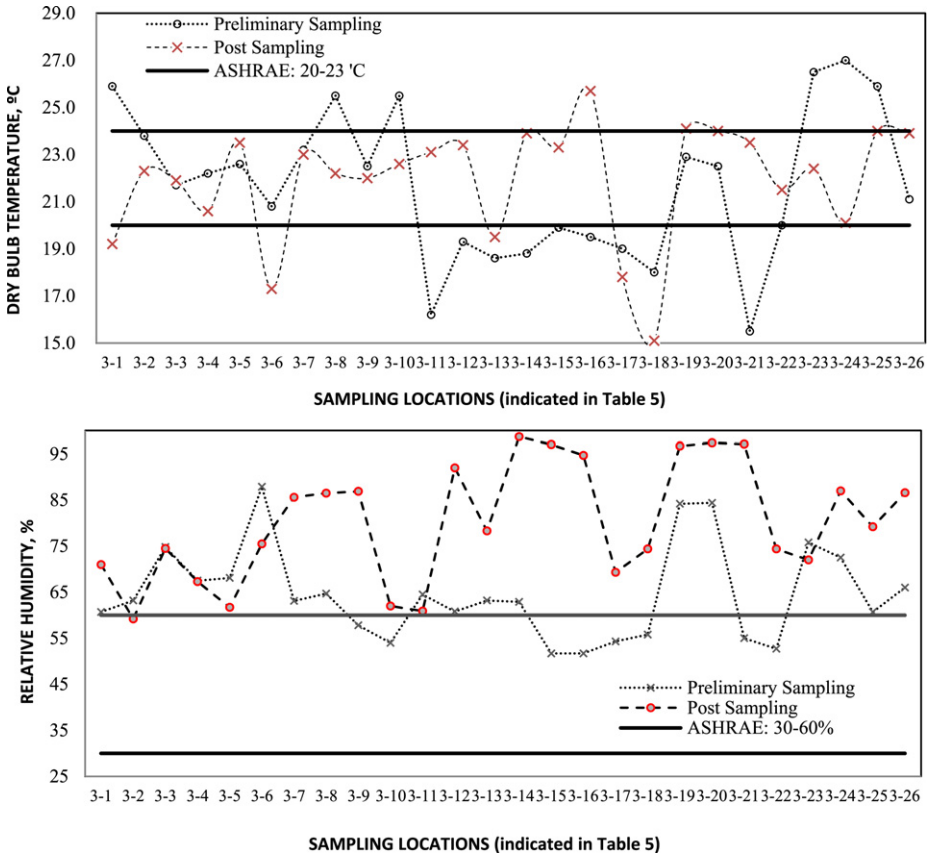

Fig. 6. Measurements for air temperature and relative humidity for critical area.

3.2. Critical area

3.2.1. Evaluation of temperature and relative humidity

The temperature and relative humidity values measured are presented in Fig. 6.

The air dry-bulb temperature recorded in the critical areas at 26 locations ranged between 15.5 °C and 25.9 °C before the decontamination, with the average temperature being 21.1 °C. The ASHRAE [24] standard suggests an operating room temperature range of 20–23 °C.

Measurements were repeated at the same locations after the decontamination process. The air dry-bulb temperature ranged between 15.1 °C and 25.7 °C, with the average temperature being 21.8 °C. From these measurements, only seven sampling locations satisfied the requirements for both pre and post decontamination.

Most measurements of relative humidity for both areas were above the recommended range [24] of 30–60% RH, with values before and after decontamination of 64.3% and 80.3%, respectively. The high humidity was probably caused by the same problems affecting the general area.

3.2.2. Evaluation of particulate matters

Fig. 7 shows the average concentrations of indoor particulates, with the highest concentration of 28 μg/m^3 before decontamination, and 10 μg/m^3 after decontamination, which is lower than the suggested limit [23,25] in the guideline, which is 150 μg/m^3. The

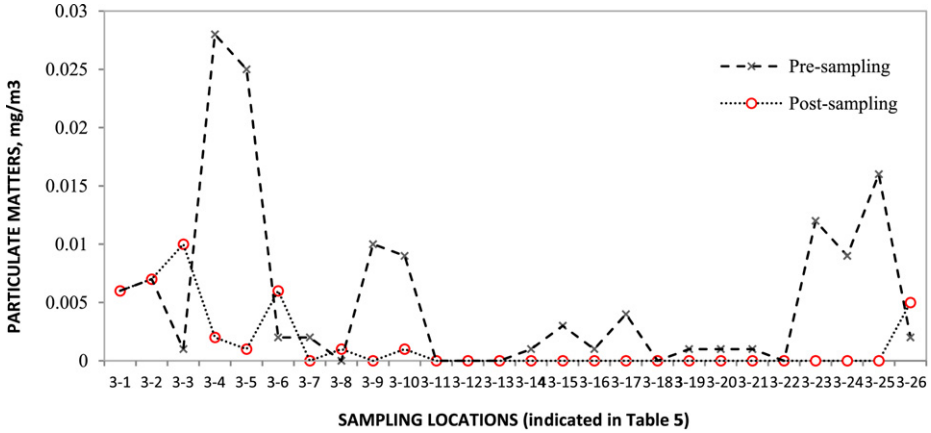

Fig. 7. Measurements for suspended particulate matters for the critical area.

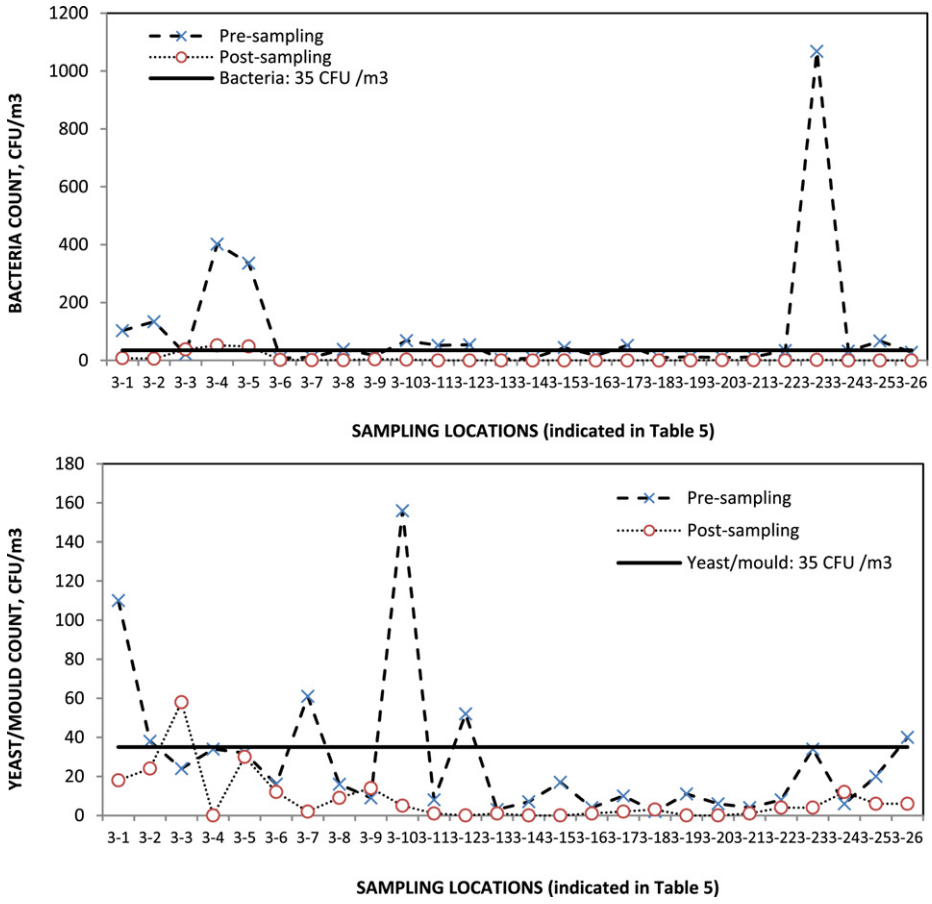

Fig. 8. Measurements of bacteria and fungus & mould counts for the critical areas.

average concentration of all locations before and after the decontamination process was similar, with values of 4.9 μg/m^3 and 1.6 μg/m^3, respectively. This has proven that particulate matter is not the main factor contributing to the reduction of the microbial count.

For the critical area, the average concentration of suspended particulate matter was reduced during the sampling after the decontamination, due to the cleaning process. The reduced microbial count may have been affected by the reduction of particulate matter.

3.2.3. *Evaluation of microbial pollutants*

For conventional operating rooms, the minimum standard for the microbial air count was 35 CFU m^{-3} when the theatre was empty [26,27]. Fig. 8 shows the measurements of bacteria count and fungus as well as the mould count for critical areas. The average bacteria count was reduced by 70%, from 70.1 CFU m^{-3} to 8.2 CFU m^{-3} (Table 1). While the average yeasts and moulds count was reduced by 30.5%, from 30.8 CFU m^{-3} to 9 CFU m^{-3} (Table 1). The bacteria count was successfully reduced to the recommended levels after decontamination, using vaporized tea tree oil. Again, the yeast and mould counts of post-sampling for some points are even higher than pre-sampling data. This is due to the same reason mentioned in sub-section 3.1.3.

4. Conclusions

The investigation into the indoor air quality of a fully air-conditioned eight-storey healthcare facility in the East Malaysia region before and after vapour decontamination has been successfully conducted. The findings can be used as an important guide for building services engineers involving in healthcare building services work. The overall results obtained from this research study on the microbial counts of bacteria, yeasts and moulds show that tea tree oil can be used as an alternative agent for vapour decontamination. This gaseous method is particularly useful for decontaminating complex furniture and equipment that is difficult to clean manually. Tea tree oil decontamination is easier and requires less equipment and procedures compared to vapour decontamination using hydrogen peroxide.

Future investigations comparing the antibacterial properties of tea tree oil with other chemical disinfectants for indoor air are required. Results from this investigation should be taken into consideration when considering methods for air decontamination in hot and humid tropical climates.

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